A Senior Honors Thesis

A Geochemical Analysis of Soils from the Rio Chagres Basin, Panama: Insight into Regional Chemical Weathering Processes and Controls

By

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Abstract

Chemical weathering is a critical process in the development of soil from rock, and is facilitated and expedited by the presence of water and heat. This process is not as well understood in moist tropical climates like that of the Rio Chagres Basin in central Panama, where conditions are ideal for rapid chemical weathering and erosion. The purpose of this project is to investigate the relationship between the resultant chemistry and extent of weathering of soils from the Rio Chagres Basin. One of the critical considerations of this study is to examine how the chemistry and composition of the soils vary with depth along a vertical cross section from surface to bedrock in different lithologies. By understanding how the chemistry changes along these profiles, insight can be obtained into what processes are occurring where, and how rapidly they are progressing.

During weathering, some ions become highly mobile, like K^+, Na^+ and Ca^{2+}, and are readily leached from source material. Other ions are fairly immobile, like Al^{3+}, and will remain in higher concentrations in the weathered product or soil. A high ratio of immobile ions to mobile ions indicates extensive weathering, where a low ratio of immobile ions to mobile ions suggests mild to moderate weathering. For this project two sample sites were chosen in non adjacent areas with unique geologic morphologies and underlying lithologies. The goal of this study is to become more aware of how climate, source rock type, topography and depth affect the progression of weathering and resultant chemistry of tropical soils.

Acknowledgements

I am truly grateful to have had the chance to work with such a remarkable group of bright and supportive people throughout the course of this project. I believe that this research opportunity has been one of the pivotal learning experiences of my undergraduate career at Ohio State.

I would sincerely like to thank Dr. Berry Lyons for his advice and wisdom throughout this research project. His enthusiasm for geochemistry is contagious, and he was always helpful and encouraging of my work while allowing me the freedom to come up with my own ideas and conclusions.

I would also like to thank Dr. Lyons research group at Byrd Polar. This amazing group of kind and supportive people always had at least one positive thing to say about my work, and were more than willing to go out of their way to offer constructive criticism and advice.

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Introduction

Chemical weathering is the principle process that transpires at the Earth's surface to convert whole bedrock into unconsolidated regolith and soil. It is also one of the most complex geochemical processes, with numerous controlling factors that work in combination to alter the chemistry of source material, produce new minerals and ultimately, create soil that allows for Earth's diverse biosphere to flourish.

Chemical weathering is the equilibrium response of igneous, metamorphic, and sedimentary rocks to an environment that is increasingly less analogous to that in which they were accreted. In essence, chemical weathering is a means to produce new minerals which are more stable to their current surroundings. As Nahon (1991) states, it is a "thermodynamic readjustment of rocks to the environmental conditions of the surface where meteoric water and atmospheric gases prevail."

Meteoric water and atmospheric gases are the main controlling factors of chemical weathering, but there are numerous other environmental influences that contribute to this process. Rates of chemical weathering are highly influenced by temperature, mineral phases of the constituent rock, mechanical fracturing, seasonality and the presence of organic matter, to name a few. Therefore, it is incredibly difficult to estimate rates of weathering or pinpoint every factor contributing to this system, as these processes are constantly in flux (White et al., 1994; Nahon, 1991). The more that is learned about these environmental influences, the clearer this extremely important geochemical process becomes. This study was designed to further investigate the progression, and mechanisms controlling chemical weathering of soils in tropical climates.

Section 1: Study Site Geology

1.1 Overview and Climate

The Rio Chagres basin (RCB) is a densely vegetated tropical watershed located in Central Panama (approx. 9ºN latitude) (Palka, 2005). This watershed spans 55,438 hectares and serves as the main supply of water to the Panama Canal. As much as 3500 mm of rain a year falls in the Chagres Basin, most of which occurs during the wet season from May to December. The dry season lasts from January to April, and very little rain falls during these months (Harmon et al., 2009). The climate is considered to be humid and tropical with all monthly temperature averages reaching above 18°C (Polka, 2005).

This warm and moist tropical climate facilitates rapid mechanical and chemical weathering, leaving deep, clay rich soils that conceal the underlying bedrock and host dense tropical vegetation at the surface. It has been estimated that the Chagres Basin loses approximately 270 tons/km/year of sediment through landscape erosion, mainly by soil creep and landsliding. (Nichols, 2005).

Exposed outcrops in the RCB are rare and are generally found only along deep cut river channels. Because of this, a complete map of the lithologies of the Chagres basin, and neighboring basins, is impossible to construct. What is known about the bedrock geology of the RCB has largely been determined by surveying stream valleys (Wörner et al., 2005).

Figure 1: The Republic of Panama. Red box denotes the Rio Chagres Basin.

Figure 2: The Rio Chagres, Panama.

1.2 Lithologies

The RCB is composed of a unique bimodal complex of Late Cretaceous to Tertiary Age (66-42 Ma) submarine lava flows, volcanic breccias and coarse grained igneous dike complexes (Wörner et al., 2005). A generalized map of the RCB igneous complex, taken from Wörner et al. (2005), can be seen in Figure 3.

The majority of the lithologies found in the RCB are mafic in composition, with some more evolved felsic melts found mainly in the upper and middle course of the Chagres River. Mafic rocks are defined as having high concentrations of magnesium (Mg) and iron (Fe), and a silica (Si) concentration of less than 52% (Wörner at al., 2005). These lithologies have been derived by partial melting of a mantle source. Mafic rocks in the Chagres watershed occur as extrusive flows as well as intrusive cross cutting dikes and igneous bodies. Common mafic rock types of the RCB are basalt, andesite, diorite, gabbro, and greenstone (Wörner et al., 2005). The most abundant lithologies across the Rio Chagres watershed are mafic in composition, and are intrusive diorite and gabbro, and regional greenstone- a hydrothemically altered andesite (Harmon et al., 2009).

Felsic rocks occur in the RCB in far less quantities than mafic rocks, and are the product of fractional crystallization of more primitive, mantle melts. Silica content of these lithologies is at least 58%, with high concentrations of alumina (Al_2O_3), sodium (Na), and potassium (K), and low concentrations of Fe and Mg. Common felsic rock types of the RCB are granite, rhyolite, granodiorite and tonalite (Wörner et al., 2005).

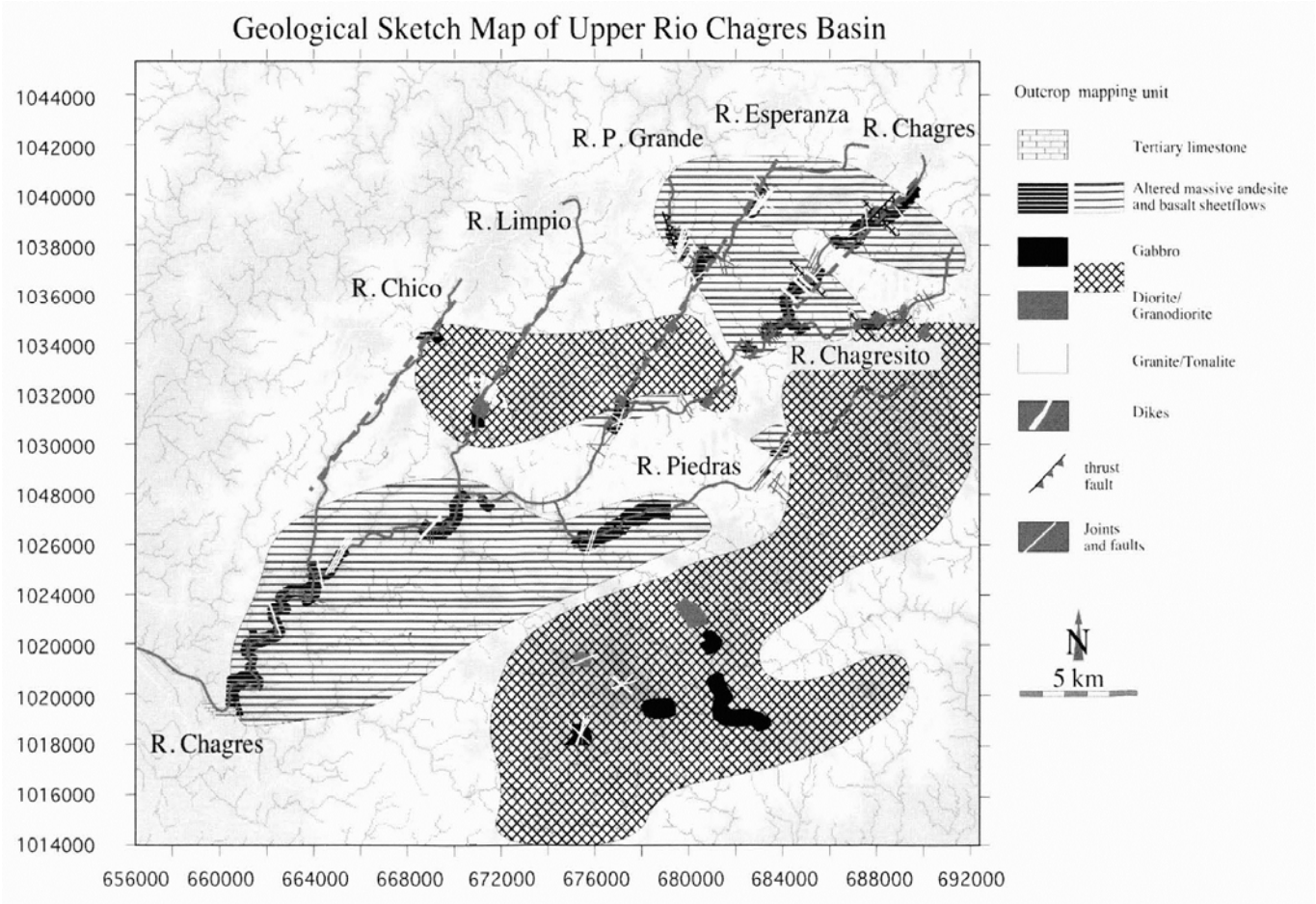

Figure 3: A generalized map of the dominant lithologies of the Rio Chagres River and contributing tributaries. From Wörner et al., (2005).

1.3 Geomorphology

The geomorphology of the region is varied and dependent highly on the local bedrock type and natural forces, especially mass movement. In one study, it was estimated that the relief of the upper Rio Chagres is approximately 800 m across a 466 km^2 area (Nichols, 2005). In the Upper Chagres Basin, over 90% of the hillslopes have angles of 45° or more (Rengers and Wohl, 2006). High angle gradients, along with the presence of deep, clay rich soils and variations in precipitation and infiltration rates, work to compromise the integrity of the slopes and facilitate landsliding and slumping on hillsides (Harrison, 2005). Steep slopes also work to confine the channels of the Chagres River and its tributaries, inhibiting broad floodplain development (Rengers and Wohl, 2006). The more mafic volcanic suites of rock found close to the headwaters of the RCB are typically more resistant to river incision and downcutting and will yield steeper gradients and more narrow river channels than felsic lithologies (Wörner et al., 2005).

1.4 Tropical Soils

Soils formed in tropical regions are unique due to the extreme conditions in which they are created. These soils are the product of extensive mechanical and chemical weathering which is facilitated by the warm and humid climate of tropical locales. Clay is a product of these weathering processes and is a major component of soils found in tropical climates (Harrison, 2005). The amount of clay minerals in a soil increases with the succession of weathering, which in turn sensitizes the soil to fluxes in moisture (Nahon et al., 1991). Kaolinite ($Al_2Si_2O_5(OH)_4$) is the dominant clay found in the soils of the RCB, and most tropical soils. To a lesser degree, halloysite (a clay with the same silica and alumina content, but a higher water content) is also

present in lower quantities (Weaver and Pollard, 1973; Harrison, 2005). Very little organic matter is found in tropical soils, and usually consists of only a thin layer capping the profiles with a total organic carbon component of less than 4% (Harrison et al., 2005).

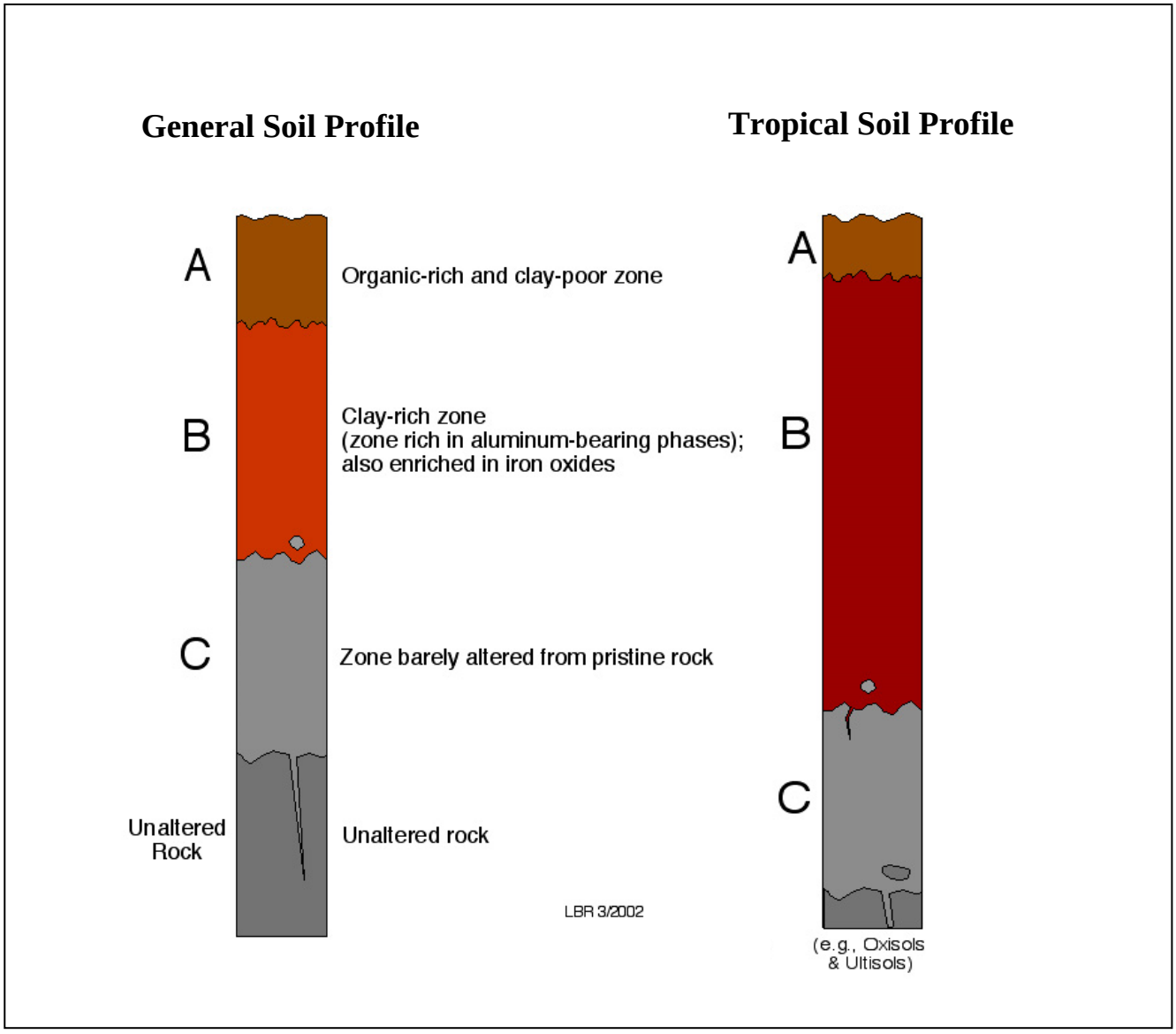

Figure 6: A simplified diagram of a typical soil profile from a temperate environment (left) compared to a profile from a tropical environment (right). Note that the "A" layer is thinner in the tropical profile and the clay-rich zone is more pronounced than that found in the general soil profile.

Section 2: Methodology

2.1 Sample Collection and Preparation

Samples were collected from 2 separate, nonadjacent soil pits in the Rio Chagres watershed. Both pits were dug by hand and sampled using clean, nylon plastic utensils. Pits were located on different topographic features and were underlain by unique lithologies. These variations are documented in Table 1. Twenty six samples were collected in all, with thirteen aliquots taken at two locations from spaced intervals of between 10 and 15 cms from the surface to close to bedrock. Soil pit 1 was dug to a depth of 183 cm, and was underlain by, and therefore weathered from, gabbro bedrock. This pit was located on a ridgecrest, which was situated at the top of a local drainage. Soil pit 9 was dug to a depth of 152 cm, and was underlain by, and weathered from, greenstone bedrock. This pit was located near a stream, on the lower slopes of the local drainage. A list of sample numbers and depth of collection is shown in Tables 2 & 3.

These samples were transported from the soil pit sites in clean plastic Ziploc ® containers to Byrd Polar Research Center at The Ohio State University. All 26 samples were then air dried for several days in disposable aluminum weighing dishes under a positive pressure hood. Dry samples were weighed and then sieved to determine particle size percentages in a No. 100 (150 μm) sieve. The separated components were combined again and crushed by hand in a ceramic mortar and pestle, and a small amount of this product was set aside for carbon and nitrogen analysis. The remainder of the samples was crushed in a Spex® CertiPrep 8515 Shatterbox for a period of 8 to 11 minutes to produce a fine powder. Each sample was then placed in a 110 ° C oven for 48 hours to drive off any remaining moisture, and then moved to a glass dessicator until ready for use. It should be noted that latex gloves were worn at all times

throughout this project when handling samples, containers, and equipment to prevent contamination.

Table 1: Sampled soil pits with their corresponding underlying rock type and local topographic feature.

Characteristic	**Soil Pit 1**	**Soil Pit 9**
Underlying lithology	**Gabbro**	**Greenstone**
Topography	**Ridge Crest**	**Stream-side**

Table 2: Soil pit 1 sample numbers and depth of collection.

Sample #	Depth (cms)
1-1	0-8
1-2	10-15
1-3	18-20
1-4	25-28
1-5	36-38
1-6	48-53
1-7	64-69
1-8	76-81
1-9	89-94
1-10	102-107
1-11	127-132
1-12	145-152
1-13	178-185

Table 3: Soil pit 9 sample numbers and depth of collection.

Sample #	Depth (cms)
9-1	0-2
9-2	4-8
9-3	10-12
9-4	16-20
9-5	30-34
9-6	40-44
9-7	50-54
9-8	60-64
9-9	86-90
9-10	100-104
9-11	116-120
9-12	132-136
9-13	150-154

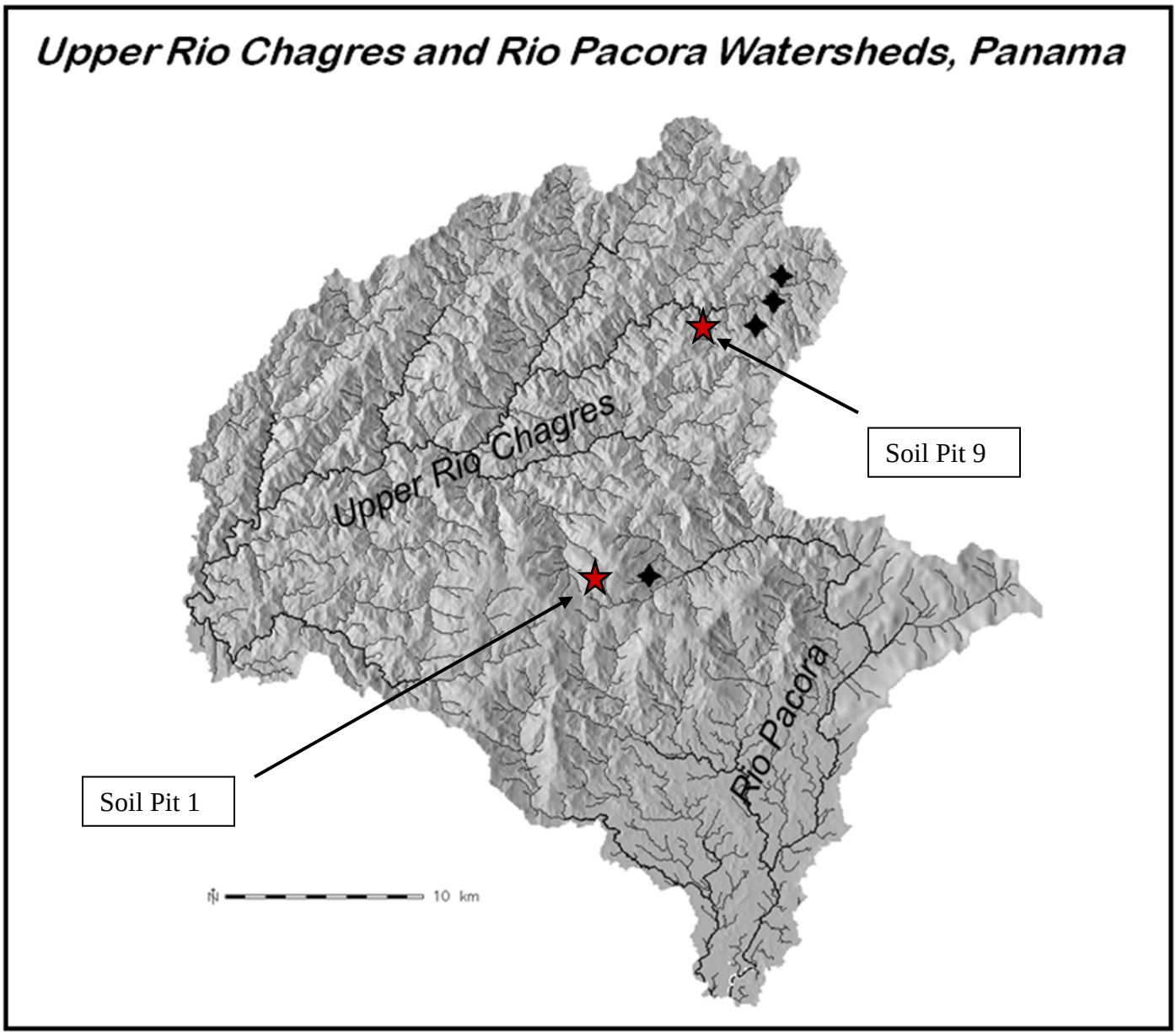

Figure 5: The Upper Rio Chagres Watershed with sample soil pit locations indicated by red stars.

2.2 Carbon and Nitrogen Analysis

Carbon (C) and Nitrogen (N) were analyzed by personnel in the School of Natural Resources at The Ohio State University. A dry combustion method of analysis was conducted using a CE instruments® NC2100 soil analyzer. Methods utilized are as described in Nelson and Soomers (1996) for C analysis, and Bremner et al. (1996) for N. Before samples were evaluated, the instrument was calibrated to a 4 point calibration curve with an atropine standard consisting of 4.84% N and 70.055% C. Samples were dried in an oven at 60° C to drive off any residual water. No more than 100 mg of dry sample was loaded into a tin capsule and run with the soil analyzer. A standard was also analyzed at the end of the run to ensure proper calibration. Precision was determined to be +/- 10% or better for all samples included in this study.

2.3 Major Element Bead Preparation

Methods utilized for the preparation of major element bead are detailed in Goldsmith et al., (2008). For this study, fused glass beads were prepared from the dried, powdered soil to be analyzed by XRF spectroscopy. In a disposable plastic weighing dish, 1.0 g of post shatterbox ground sample was combined with 10.0 g of SpectroCertified® Pre-Fused Fusion Flux Lithium Tetraborate (100% $Li_2B_4O_7$). These ingredients were mixed with a clean aluminum spatula until homogenous. This mixture was then transferred into a platinum crucible and loaded into a Phillips® Perl'x 3® automatic bead machine for ignition for 4 minutes at 800˚C, 4 minutes at 1100˚C, and 8 minutes at 1150˚C. The molten, homogenous product of these subsequent ignitions was cast in a platinum casting dish, air cooled to form a solid glass bead, labeled, and stored in a glass dessicator until ready for analysis. Any fused glass bead displaying

imperfections or deformities (i.e., cracks, mottled appearance, incomplete sample dissolution), were discarded.

2.5 XRF Analysis

The fused major element beads were analyzed with a PANalytical® MagiX Pro® XRF spectrometer for major and minor oxide composition. Compositions of the samples were reported as oxide percents by weight for major elements. Each sample was run 3 times and an average of the trials was taken. These averaged values were also normalized to XRF calculated loss of ignition (LOI) values. A USGS standardized fused glass bead, BCR-2 (Columbia River Basalt) of known composition was run every 6 samples to ensure correct machine calibration.

To determine the precision of these measurements, relative standard deviations were calculated from the three runs of major element oxide beads. Relative standard deviations ranged from ±0% to ±10.2%, (Al_2O_3), but the majority were ±0.5% or better. Tables displaying the average elemental compositions, as well as the relative standard deviations, can be found in Appendix II.

Section 3: Calculations

3.1 The Chemical Index of Alteration

The Chemical Index of Alteration (CIA), a weathering index described in Price, et al. (2003), was utilized to calculate the degree of weathering for the 26 total samples collected.

$$\textbf{Chemical Index of Alteration (CIA)} = \frac{(Al_2O_3)}{(Al_2O_3+K_2O+CaO+Na_2O)} * 100$$

Calculated from major oxide percentages, this formula assigns a unitless, numeric value to represent the degree of weathering the source material has undergone. As the CIA value increases, the more intense the chemical weathering of the material has progressed. This formula is based on the theory that during chemical weathering, mobile elements (i.e. K, Ca and Na) are readily leached from the parent material, and immobile elements (i.e. Al) are not. A higher CIA value therefore indicates that more K, Ca and Na have been lost from the parent material in relation to Al. A value of less than or equal to 50 embodies the ideal value of pristine, unweathered material, and 100 represents the optimum weathered value (Price et al., 2003). A value of 100 is only attainable if *all* K, Ca and Na have been leached from the source material.

Section 4: Results

4.1 Grain Size Analysis

The grain size analysis, as noted in the methodology section of this text, was conducted with a sieve that allowed for particles which were 150 μm in diameter or less to pass through. According to the Udden-Wentworth grain size classification scale (Appendix I), particles of 150 μm fall in the "Fine Sand" category. Particles smaller than 150 μm are titled "very fine sand", "silt" and "clay." Grains which are greater than 150μm are various grades of sand and gravel. It should be noted that no particles from any of the 26 sample aliquots could be considered larger than a "granule" (2-4 mm) on the Wentworth scale. For the purpose of this document, all particles from here on out referred to as "fine" shall be classified as less than or equal to 150 μm in diameter, and all particles considered "coarse" shall be classified as having a diameter greater than 150μm.

For both sample soil sites, the percentage of the sample that was coarse grained was plotted against median depth. This yielded a vertical grain size profile for the pits, of which the results can be found in Figures 6 & 7. Figure 6 depicts the grain size profile for pit 1. It was noted in the field guide of the sampler that there was a visible transition in this soil pit from the "A" soil horizon to red clay at 40 cms deep. This boundary is denoted on Figure 5 with a dashed black line. No such differentiation was recorded for pit 9.

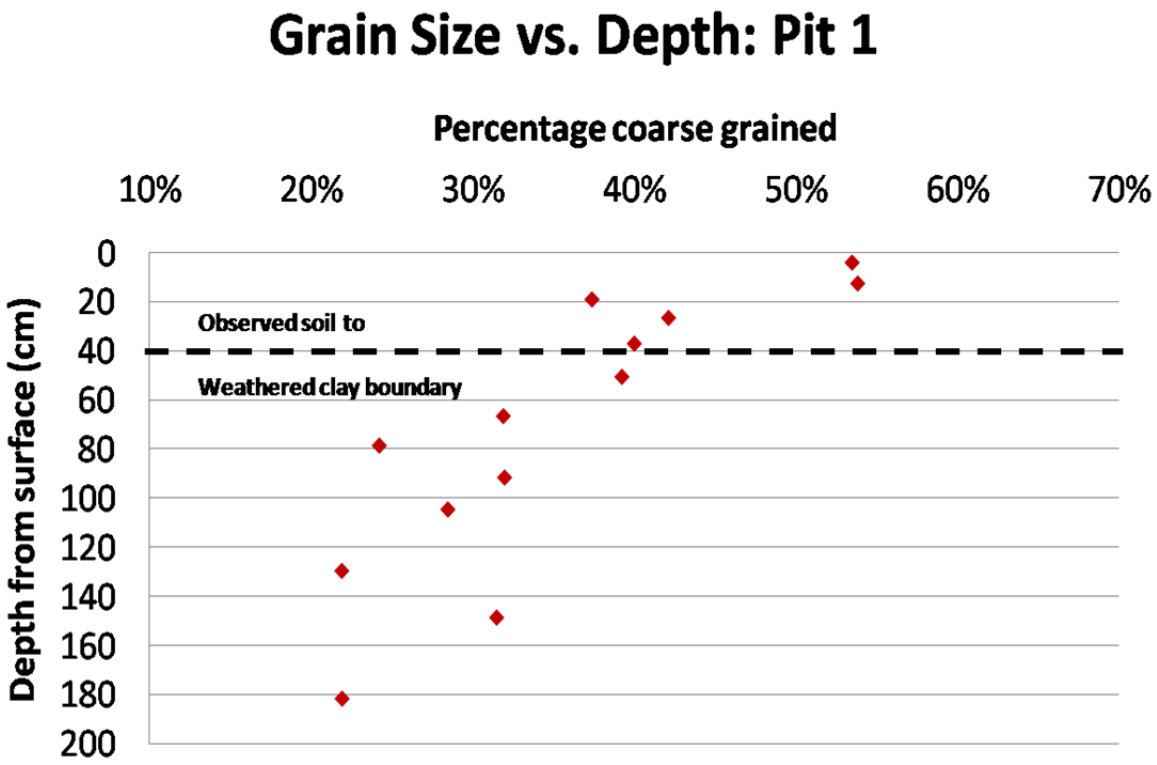

Figure 6: Coarse grain component of soil from pit1 plotted vs. sample depth. Dashed line indicates observed boundary between the upper most "A" soil horizon and lower red clay.

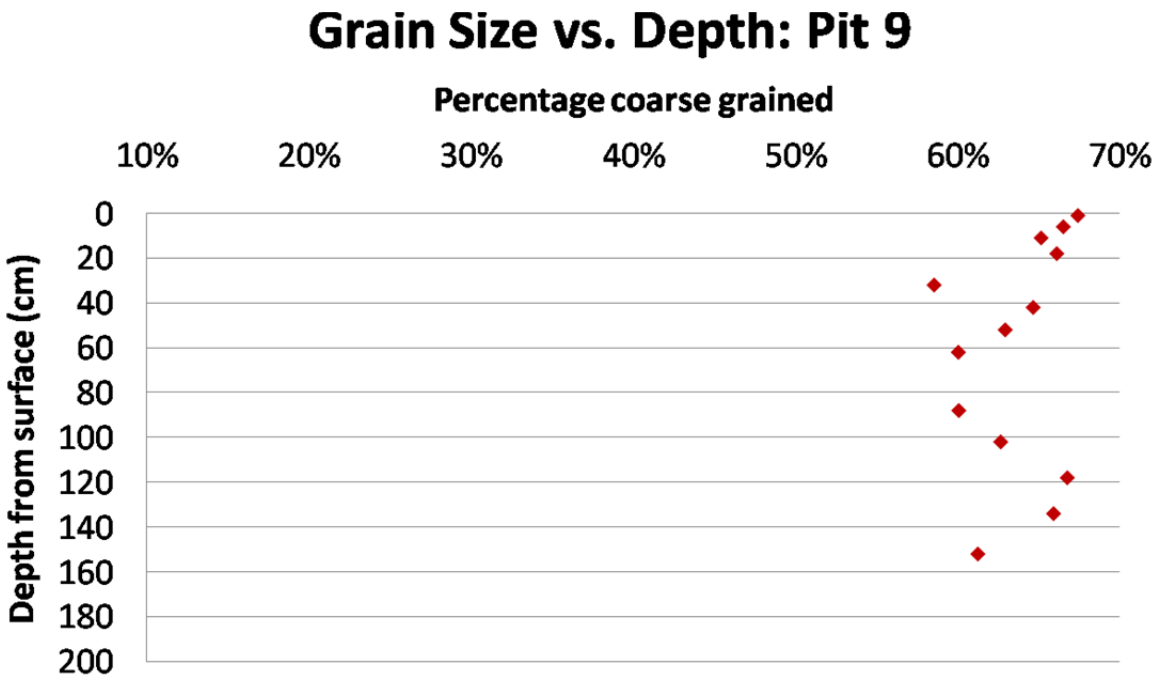

Figure 7: Coarse grain component of soil from pit 9 plotted vs. sample depth.

The grain size of pit 1 contains more fines and fluctuates with depth, as compared to pit 9. There is a definite, observable inverse relation between depth and the percentage of coarse grained material for pit 1 (material fines downwards). The r^2 value for this data set is 0.70, ($p<0.05$) which indicates a moderately high correlation of data points. For pit 9, the r^2 value is 0.06, ($p=.42$) indicating there is no valid trend for these two variables. No correlation between grain size and sampled depth can be concluded for pit 9.

4.2 Chemical Index of Alteration

The CIA value of each sample was calculated and plotted as a function of median depth to yield a vertical weathering profile (Figures 8 & 9). The correlating underlying bedrock CIA was also calculated from chemical analyses of rocks from central Panama as detailed in Harmon et al., (2009). Because these soils originate from the local bedrock, these CIA values, 54.1 for gabbro and 55.2 for greenstone, represent the ideal, unweathered and unaltered starting value of their corresponding, overlying soils. The gabbro and greenstone CIA values were plotted as vertical lines on Figures 8 & 9, respectively. Any point plotting to the right of the bedrock CIA line on either of these graphs has, by definition, been weathered.

For soil pit 1 (Figure 8), CIA values at all depths are extremely high. This indicates that there has been intense chemical weathering of these soils. CIA values increase downprofile, which signifies that the degree of weathering is increasing with depth. The observed soil to weathered clay boundary has also been plotted as a dashed line. CIA values above this line are lower, and below this transition, they more elevated. Clays are the product of intense chemical, and mechanical weathering and it is intuitive that this lower red clay zone would be highly depleted of mobile elements, yielding a high CIA.

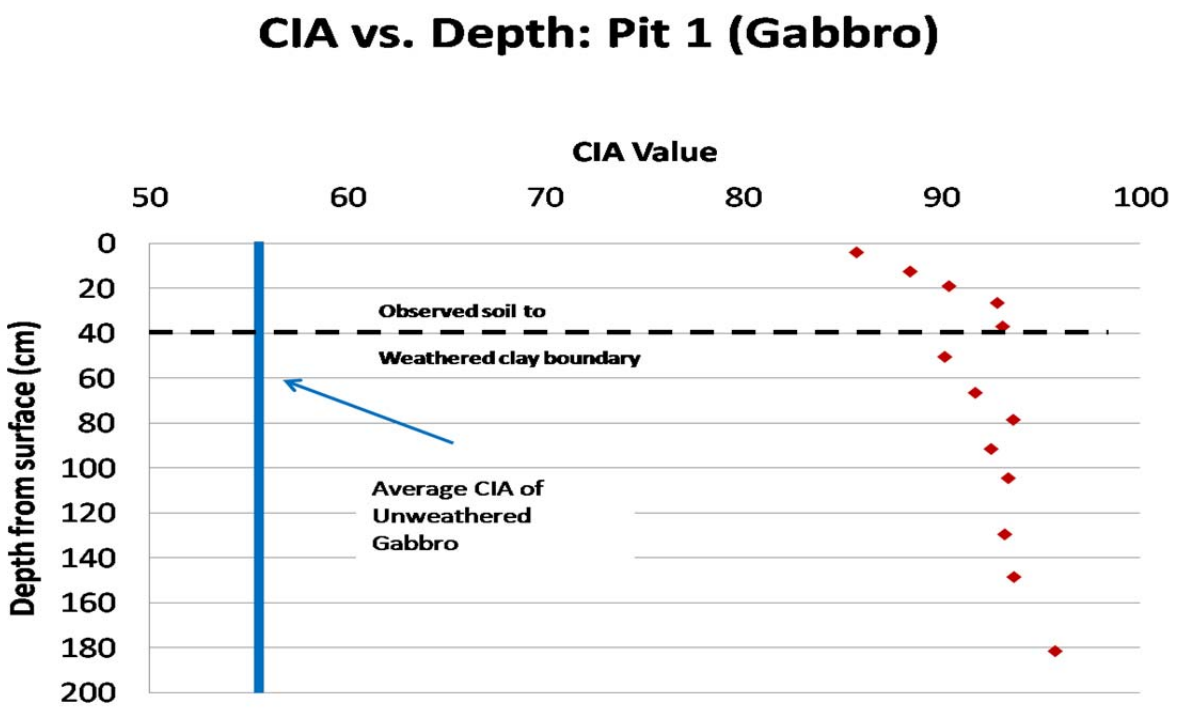

Figure 6: CIA profile for soil pit 1

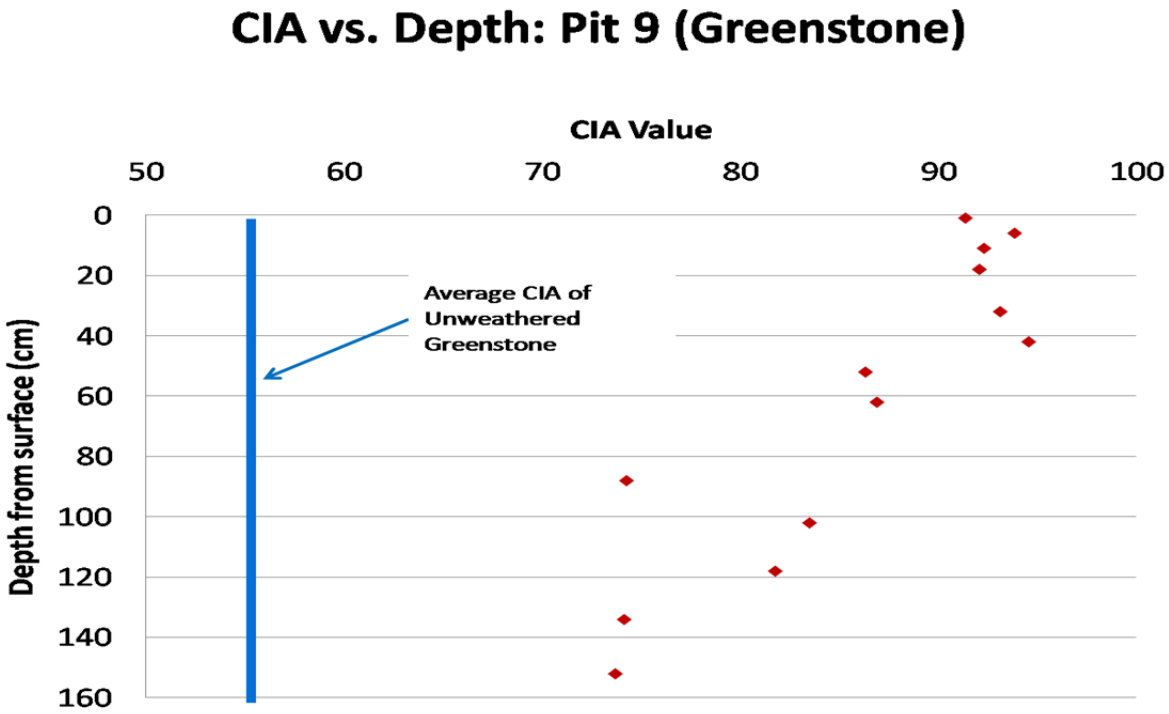

Figure 7: CIA profile for soil pit 9

Interestingly enough, soil pit 9 does not show a similar pattern of weathering to pit 1. It should be noted that pit 9 has lower CIA values in general, indicating less intensive weathering has progressed at this site as compared to pit 1. Surface soils appear to be highly depleted in mobile ions, and deeper soils are more enriched. Therefore, chemical weathering decreases down profile with the greatest degree of weathering occurring in surface soils. This is a more typical, and expected soil profile, as surface processes (bioturbation, runoff, heating and cooling) are thought to expedite weathering (Atkinson, 2004). It is expected that deeper soils will have a chemistry closer to the underlying bedrock (Nahon, 1991). CIA values of soils from greater depths of pit 9 are more similar to the CIA of the unweathered greenstone bedrock than surface soils, which fits with this trend.

4.3 Carbon and Nitrogen data

The percentage of carbon (C) and nitrogen (N) for samples from pit 1 and pit 9 are plotted as a function of depth in Figures 9 &10. The biologically active zone (BAZ), as described in Harrison, (2005), is also depicted on the graphs and is highlighted in yellow. The BAZ is described as the zone which is affected by biological and natural forces such as burrowing and turbation by roots. In this part of Panama, the BAZ is defined as the top 60 cm of regolith (Harrison, 2005).

It can be seen in both soil profiles that in the BAZ carbon and nitrogen experience elevated concentrations, which level off to a steady base level directly beneath. It should be noted that none to very little of this carbon is believed to be originating from source bedrock, as no carbonate lithologies have been identified in this area, and carbon is almost completely absent

from the sampled rocks of this region (Wörner et al., 2005). All carbon and nitrogen in soils from this study area is believed to be sourced strictly from organic matter.

Both carbon and nitrogen are more plentiful in samples from pit 9. This can be attested to the type of vegetation which grows at this locale (Jobbagy and Jackson, 2000). Pit 9 is located on a grassy lowland area, where organic matter is added throughout the year through decay of overlying vegetation as well as additions through mass movement from adjacent, high relief slopes. Pit 1, in contrast, is located on cleared land at the top of a high relief slope. There is less plentiful vegetation at this site and therefore, less leaf litter, grass, or fibrous, woody organic material decomposing and releasing C and N into the soils of Pit 1. It is also possible that a portion of this accumulation of C and N is removed through mass wasting and deposited downslope, further depleting the surface soils of these elements, and in turn enriching low lying slopes (Lyons, personal communications).

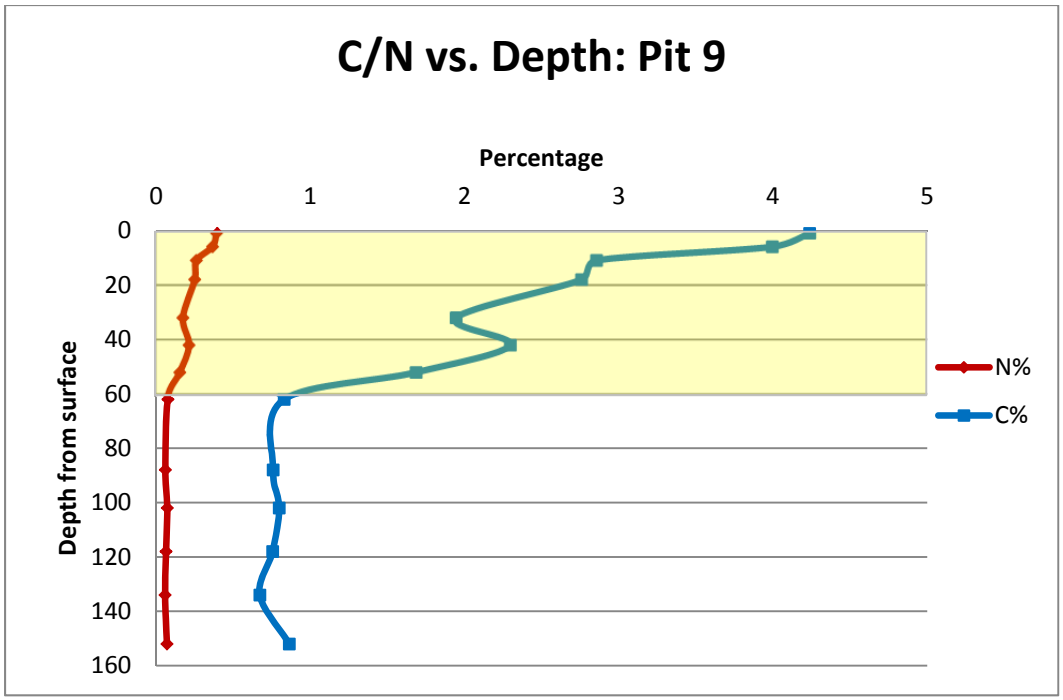

Figure 8: Carbon and nitrogen percentage plotted against sampled depth for soil pit 1. BAZ is indicated by yellow highlighted area.

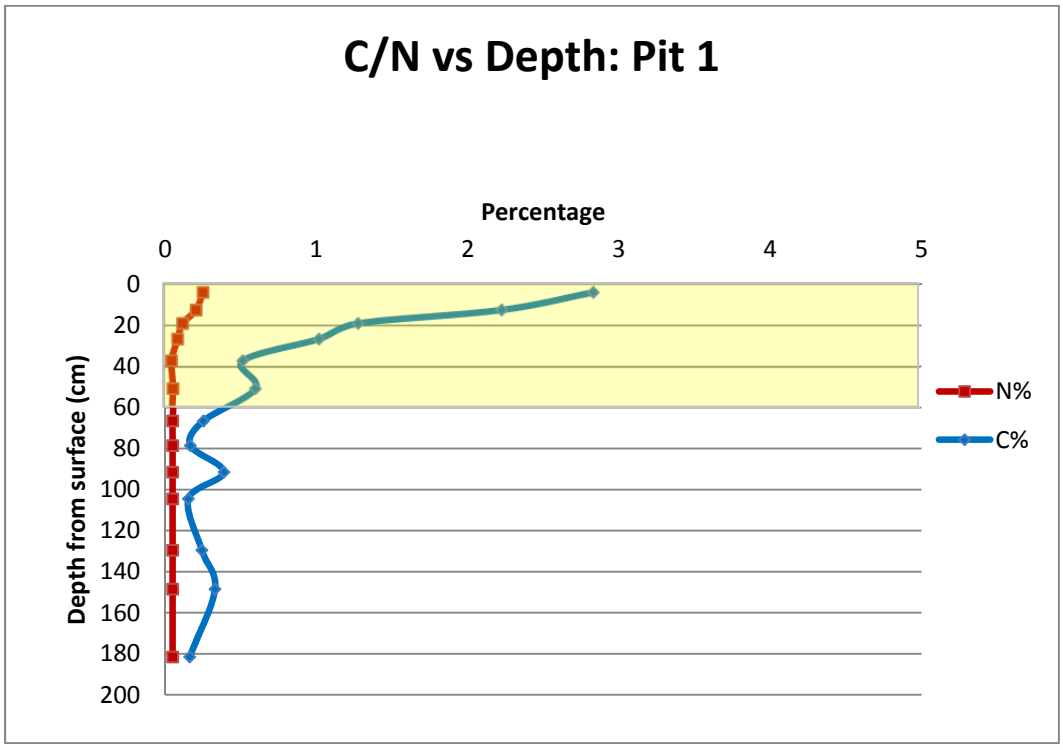

Figure 9: Carbon and nitrogen percentage plotted against sampled depth for soil pit 9. BAZ is indicated by yellow highlighted area.

Section 5: Discussion

This study has yielded highly unexpected results, as the two experimental soil pits that were examined exhibited different trends in grain size and CIA values with depth. This can be attested to the distinctive and unique suite of chemical weathering processes carried out at their respective sample collection sites, which can further be linked to the topographic features on which the pits were sampled (ridgecrest vs. streamside).

Soil pit 1, which was located at a higher elevation, displays more intense weathering overall, as shown not only by the CIA weathering profile, but the grain size profile as well. Soils from pit 1 are finer grained than that of pit 9 which can be attributed to two factors. Enhanced mechanical, as well as chemical weathering produces smaller particle sizes by breaking apart and dissolving material. Clays, which have a very fine particle size, are the end product of the progression of soil weathering. In Harrison (2005), the author states that soils on upper slopes, like those of pit 1, are weathered to a higher degree than soils on lower slopes. Overall, pit 1 shows a higher average weathering than that of pit 9, which agrees with these findings.

The CIA weathering profile of pit 1, which reveals a higher degree of weathering with increased depth, displays a vertical succession of alteration which is distinctly different than that of pit 9. It can be concluded that the mechanisms of chemical weathering progressing at these two locations are different, yielding unique weathering profiles. The largest chemical weathering forces believed to be in operation in the vicinity of pit 1 are through-flow and groundwater interaction. These processes are responsible for the leaching of mobile ions from deep soils instead of surface soils, producing the profile attributed to pit 1 (Figure 6).

Soils with high clay contents are highly susceptible to fluxes in wetting and drying, conditions that are present in the RCB due to the fluctuations in precipitation during the wet and

dry season. This moisture flux will create cracks in the clayey soil, opening channels of preferred movement for water to percolate deep into the ground. Meteoric water, as well as groundwater, will effectively leach the most mobile ions from soils through chemical weathering. Since soil pit 1 is located on a slope, the water, and therefore the ions, will be removed from the material due to gravity induced flow downhill. This process is illustrated in Figure 10.

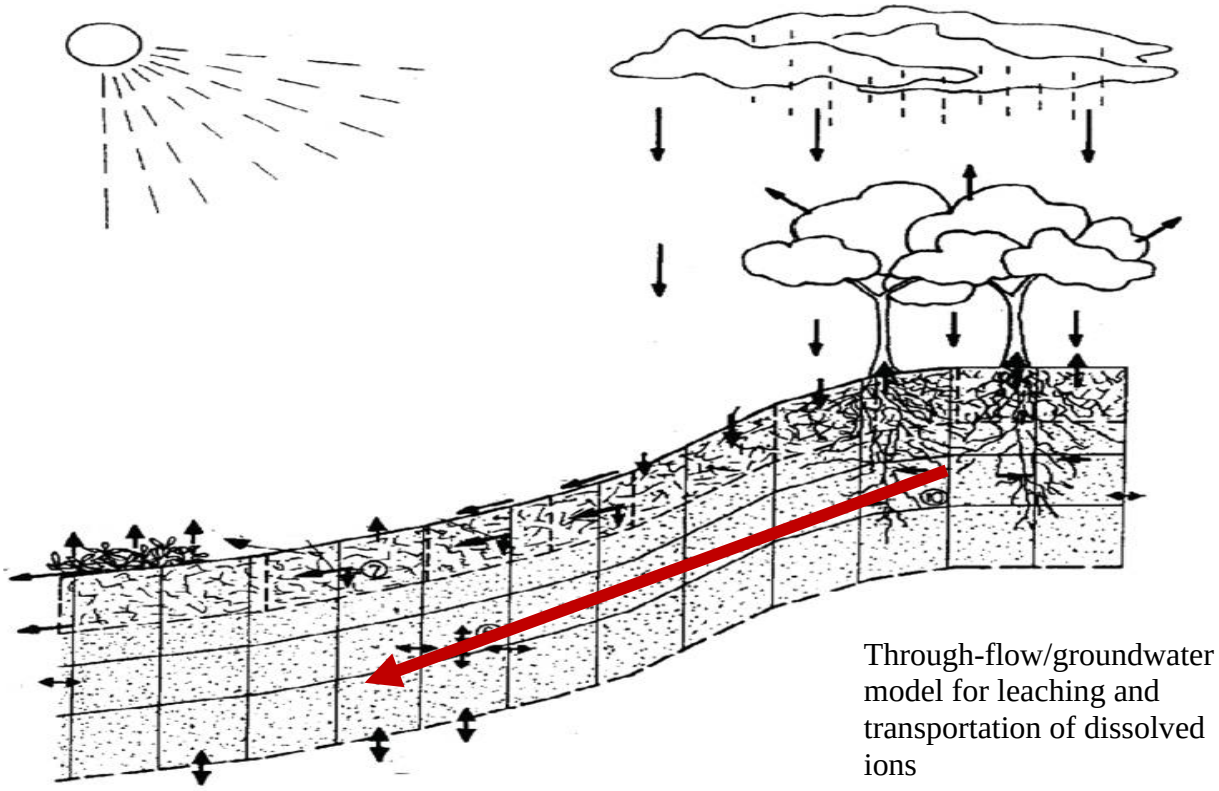

Figure 10. Diagram depicting the process of through-flow, which is thought to be a major contributor to the process of chemical weathering of slopes of the RCB. Modified from Bronstert et al. (1999).

Along with through-flow, mass movement is also believed to be a variable in producing the signature profiles of pit 1. In theory, the surface soils should be the most weathered horizon of a vertical soil profile because they are in constant contact with atmospheric gases and exposed to higher volumes of meteoric water, which Nahon (1991) concluded were the most important

weathering agents. The surface soils of pit 1 show a lesser degree of weathering than the surface soils of pit 9. This can be attributed to the removal of the uppermost plane of material from pit 1 by gravity driven flows downslope.

Landslides, as previously described, are a major landscape altering process in the RCB (Harrison, 2005). It is likely that surface processes are effectively weathering the topmost materials of pit 1, but these altered products are constantly being removed due to mass movement downhill. This in turn will reveal a fresh surface to the atmosphere, encouraging weathering to progress. It can be concluded that the process of mass movement allows for enhanced weathering by surface regeneration, and this cycle of leaching and removal permits for more dissolved ions to be removed from the soil.

The weathering profile of Pit 9 can also been attributed to the process of mass movement. Previous grain size and elemental distribution analysis by Guariguata, (1990) of soil from fresh landslides in Puerto Rico, which has a similar climate and topography to the RCB, showed a comparable profile to that of pit 9. In particular, fresh landslides exhibited no variation of grain size and an increase of cation values with depth. The CIA values of pit 9 increase with depth, which is indicative of a downward increase of cation concentrations (like K, Ca and Na).

The surface soils of this pit are more weathered than deep soils. Along with normal in-situ shallow depth weathering processes, it is likely that weathered landslide debris from upper slopes, as previously discussed, are added to the top of this profile. It is also likely that stream action is affecting the leaching of surface soils at the site, as pit 9 is located by a stream. Channels of the RCB are highly confined due to the resistance of the mafic bedrock in the area. The floodplain directly adjacent to the stream near the location of pit 9 would be affected by heavy rainfall and runoff events if the stream overflowed its banks. Weathering through

dissolution and leaching of the uppermost surface soils would occur during flooding events due to pooled water which would infiltrated the floodplain surface. After the flooding subsided, the ions from this surface material would be effectively removed with the outflow of water back to the stream channels.

Although the grain size and CIA profiles from both locations are different, the C and N profiles display similar trends. It can be concluded that the carbon and nitrogen composition of soil is not largely affected by the same chemical weathering processes which influence other elemental components of soils. The concentrations of C and N are more influenced by the type of vegetation and decomposition rates at the sample site than the topography and mechanical or chemical processes previously discussed.

It is inconclusive whether the bedrock types of this area are affecting how quickly or extensively chemical weathering is progressing. The extreme differences in the soil CIA and grainsize profiles of the sampled pits examined in this study are most likely a result of differences in topography and relief, not bedrock composition. The lithologies from the sites sampled in this study are not chemically variable enough to attribute variations in progression of weathering to rock type alone.

Section 6: Conclusions

- Soils studied for this project from the RCB were highly depleted in mobile ions compared to source material, indicating extensive weathering of this region has occurred.

- The extent of chemical weathering of soils from the RCB is most affected by the elevations and geomorphology of the site. Soils on slopes, and at higher elevations, experience increased weathering compared with low lying soils.

- Carbon and Nitrogen are not affected by the same processes as other elements considered in this study

- Lithology, at least between rocks of similar, mafic composition, was not determined to be a dominant variable contributing to resultant soil chemistry in this study.

Section 8: Future Work

There is still much to be understood about the complex process of chemical weathering in tropical environments. Future work should include the collection and analysis of more soils from the Chagres Basin. To fully assess the role of topography and underlying lithology on chemical weathering of this watershed, at least one sample representing all possible combinations of topographic feature and underlying lithology of the RCB (i.e., a soil formed from Diorite found on a ridge crest as well as a soil formed from a Diorite from a low slope area) should be collected and analyzed. A more complete data set would strengthen the arguments put forth by this document.

In the near future, trace element data and isotopic C and N will be applied to this project to better understand the geochemistry of these soils. A soil derived from a felsic lithology is also to be analyzed to assess the differences in resultant soil chemistry accreted from felsic vs. mafic rocks. This data can additionally be correlated with previous dissolved ion data of the Chagres River and neighboring streams, as documented in Harmon et al., (2009), to link soil weathering with the chemistry of waterways of the RCB.

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Appendix I

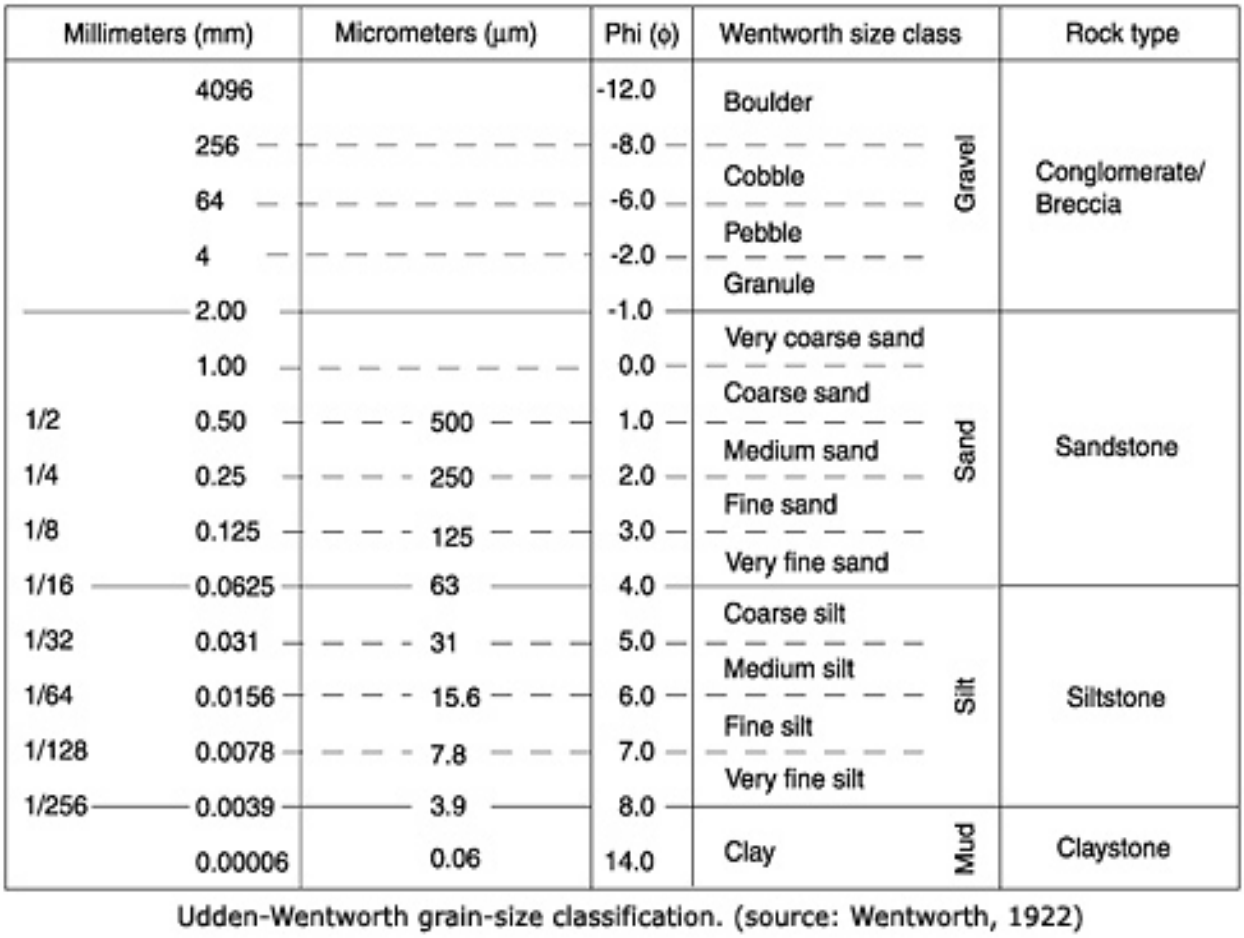

Figure 11: Udden-Wentworth grain-size classification diagram.

Appendix II

Sample name	Loss On Ignition (%)	Sum of conc. (%)		Al2O3 Al (%)	SiO2 Si (%)	Fe2O3 Fe (%)	CaO Ca (%)	TiO2 Ti (%)	MgO Mg (%)	MnO Mn (%)	K2O K (%)	Na2O Na (%)	P2O5 P (%)
LH-(1-13) 9-16-08	25.5599		concentration	21.913	35.145	14.292	0.372	0.944	0.828	0.103	0.195	0.399	0.14
LH-(1-13) 9-16-08	26.0653		concentration	21.707	34.887	14.26	0.371	0.937	0.831	0.103	0.194	0.4	0.138
LH-(1-13) 9-16-08	26.1597		concentration	21.672	34.82	14.25	0.369	0.941	0.84	0.103	0.196	0.401	0.138
(1-13) AVERAGE	25.9283	74.072	**Avg**	21.764	34.9507	14.2673	0.3707	0.9407	0.833	0.103	0.195	0.4	0.1387
			LOI norm conc	16.121	25.8886	10.5681	0.2746	0.6968	0.617	0.076	0.144	0.296	0.1027
			rel std dev	0.60%	0.49%	0.15%	0.41%	0.37%	0.75%	0.00%	0.51%	0.25%	0.83%
LH-(1-12) 5-10-09	25.7571		concentration	20.796	39.663	10.18	0.484	0.777	0.974	0.248	0.32	0.601	0.09
LH-(1-12) 5-10-09	25.7937		concentration	20.871	39.567	10.163	0.483	0.778	0.966	0.248	0.32	0.61	0.091
LH-(1-12) 5-10-09	25.8754		concentration	20.773	39.589	10.17	0.48	0.775	0.968	0.248	0.32	0.604	0.088
(1-12) AVERAGE	25.8087	74.191	**Avg**	20.8133	39.6063	10.171	0.4823	0.7767	0.969	0.248	0.32	0.605	0.0897
			LOI norm conc	15.4417	29.3844	7.54599	0.3578	0.5762	0.719	0.184	0.237	0.449	0.0665
			rel std dev	0.25%	0.13%	0.08%	0.43%	0.20%	0.43%	0.00%	0.00%	0.76%	1.70%
LH-(1-11) 9-16-08	25.7113		concentration	19.809	38.462	12.537	0.532	0.746	0.983	0.086	0.306	0.608	0.117
LH-(1-11) 9-16-08	25.7273		concentration	19.732	38.556	12.502	0.534	0.749	0.985	0.086	0.308	0.599	0.117
LH-(1-11) 9-16-08	25.6798		concentration	19.753	38.576	12.519	0.532	0.747	0.983	0.086	0.31	0.596	0.117
(1-11) AVERAGE	25.7061	74.294	**Avg**	19.7647	38.5313	12.5193	0.5327	0.7473	0.984	0.086	0.308	0.601	0.117
			LOI norm conc	14.6839	28.6264	9.3011	0.3957	0.5552	0.731	0.064	0.229	0.447	0.0869
			rel std dev	0.20%	0.16%	0.14%	0.22%	0.20%	0.12%	0.00%	0.65%	1.04%	0.00%
LH-(1-10) 5-10-09	23.2501		concentration	19.702	41.275	12.262	0.48	0.722	0.949	0.21	0.326	0.593	0.126
LH-(1-10) 5-10-09	23.3699		concentration	19.709	41.122	12.278	0.476	0.722	0.961	0.21	0.325	0.592	0.128
LH-(1-10) 5-10-09	23.3693		concentration	19.693	41.184	12.24	0.479	0.723	0.953	0.21	0.325	0.593	0.128
(1-10) AVERAGE	23.3298	76.67	**Avg**	19.7013	41.1937	12.26	0.4783	0.7223	0.954	0.21	0.325	0.593	0.1273
			LOI norm conc	15.1051	31.5833	9.39977	0.3667	0.5538	0.732	0.161	0.249	0.454	0.0976
			rel std dev	0.04%	0.19%	0.16%	0.44%	0.08%	0.64%	0.00%	0.18%	0.10%	0.91%
LH-(1-9) 5-9-09	21.9335		concentration	17.619	43.883	13.234	0.47	0.607	0.895	0.151	0.354	0.606	0.146
LH-(1-9) 5-9-09	21.7715		concentration	17.597	44.055	13.249	0.467	0.605	0.893	0.149	0.354	0.607	0.147
LH-(1-9) 5-9-09	22.2047		concentration	17.472	43.767	13.247	0.466	0.609	0.89	0.151	0.354	0.588	0.148
(1-9) AVERAGE	21.9699	78.03	**Avg**	17.5627	43.9017	13.2433	0.4677	0.607	0.893	0.15	0.354	0.6	0.147
			LOI norm conc	13.7042	34.2565	10.3338	0.3649	0.4736	0.697	0.117	0.276	0.468	0.1147
			rel std dev	0.45%	0.33%	0.06%	0.45%	0.33%	0.28%	0.77%	0.00%	1.78%	0.68%
LH-(1-8) 9-11-08	26.0301		concentration	18.968	38.118	13.588	0.436	0.762	0.879	0.132	0.284	0.549	0.141
LH-(1-8) 9-11-08	26.3192		concentration	18.775	37.993	13.606	0.439	0.763	0.887	0.132	0.284	0.551	0.138
LH-(1-8) 9-11-08	27.2133		concentration	18.332	37.58	13.573	0.438	0.762	0.886	0.132	0.284	0.547	0.14
(1-8) AVERAGE	26.5209	73.479	**Avg**	18.6917	37.897	13.589	0.4377	0.7623	0.884	0.132	0.284	0.549	0.1397
			LOI norm conc	13.7345	27.8464	9.98508	0.3216	0.5602	0.65	0.097	0.209	0.403	0.1026
			rel std dev	1.74%	0.74%	0.12%	0.35%	0.08%	0.49%	0.00%	0.00%	0.36%	1.09%

Sample name	Loss On Ignition (%)	Sum of conc. (%)		Al2O3 Al (%)	SiO2 Si (%)	Fe2O3 Fe (%)	CaO Ca (%)	TiO2 Ti (%)	MgO Mg (%)	MnO Mn (%)	K2O K (%)	Na2O Na (%)	P2O5 P (%)
LH-(1-7) 5-9-09	27.4079		concentration	17.185	38.871	13.081	0.487	0.707	0.905	0.141	0.338	0.645	0.119
LH-(1-7) 5-9-09	28.6567		concentration	16.477	38.354	13.053	0.483	0.703	0.902	0.141	0.337	0.659	0.118
LH-(1-7) 5-9-09	30.7383		concentration	15.42	37.42	12.95	0.482	0.7	0.913	0.139	0.334	0.669	0.118
(1-7) AVERAGE	28.9343	71.066	**Avg**	16.3607	38.215	13.028	0.484	0.7033	0.907	0.14	0.336	0.658	0.1183
			LOI norm conc	11.6268	27.1578	9.25844	0.344	0.4998	0.644	0.1	0.239	0.467	0.0841
			rel std dev	5.43%	1.92%	0.53%	0.55%	0.50%	0.63%	0.82%	0.62%	1.83%	0.49%
LH-(1-6) 5-9-09	34.2997		concentration	14.685	35.747	11.777	0.49	0.676	0.939	0.173	0.317	0.658	0.118
LH-(1-6) 5-9-09	37.5904		concentration	13.078	34.226	11.656	0.479	0.669	0.941	0.17	0.312	0.645	0.116
LH-(1-6) 5-9-09	39.7859		concentration	12.007	33.233	11.535	0.478	0.663	0.942	0.168	0.308	0.648	0.117
(1-6) AVERAGE	37.2253	62.775	**Avg**	13.2567	34.402	11.656	0.4823	0.6693	0.941	0.17	0.312	0.65	0.117
			LOI norm conc	8.32183	21.5957	7.31702	0.3028	0.4202	0.591	0.107	0.196	0.408	0.0734
			rel std dev	10.17%	3.68%	1.04%	1.38%	0.97%	0.16%	1.48%	1.44%	1.05%	0.85%
LH-(1-5) 9-11-08	25.0555		concentration	19.04	38.596	13.595	0.456	0.696	0.895	0.458	0.321	0.624	0.131
LH-(1-5) 9-11-08	25.0735		concentration	19.001	38.628	13.576	0.463	0.694	0.903	0.457	0.32	0.627	0.129
LH-(1-5) 9-11-08	25.3377		concentration	18.844	38.543	13.552	0.459	0.694	0.902	0.457	0.319	0.632	0.13
(1-5) AVERAGE	25.1556	74.844	**Avg**	18.9617	38.589	13.5743	0.4593	0.6947	0.9	0.457	0.32	0.628	0.13
			LOI norm conc	14.1918	28.8817	10.1596	0.3438	0.5199	0.674	0.342	0.24	0.47	0.0973
			rel std dev	0.55%	0.11%	0.16%	0.76%	0.17%	0.48%	0.13%	0.31%	0.64%	0.77%
LH-(1-4) 9-16-08	26.5442		concentration	17.744	38.925	12.984	0.471	0.693	0.863	0.615	0.287	0.617	0.124
LH-(1-4) 9-16-08	29.4552		concentration	16.893	37.012	12.95	0.434	0.698	0.831	0.614	0.273	0.59	0.12
LH-(1-4) 9-16-08	29.3865		concentration	16.823	37.119	12.965	0.439	0.695	0.843	0.613	0.273	0.594	0.12
(1-4) AVERAGE	28.462	71.538	**Avg**	17.1533	37.6853	12.9663	0.448	0.6953	0.846	0.614	0.278	0.6	0.1213
			LOI norm conc	12.2712	26.9593	9.27586	0.3205	0.4974	0.605	0.439	0.199	0.429	0.0868
			rel std dev	2.99%	2.85%	0.13%	4.48%	0.36%	1.91%	0.16%	2.91%	2.43%	1.90%
LH-(1-3) 9-11-08	28.0171		concentration	16.372	39.79	11.909	0.689	0.639	0.956	0.328	0.305	0.741	0.128
LH-(1-3) 9-11-08	27.8858		concentration	16.439	39.822	11.939	0.683	0.638	0.961	0.33	0.304	0.745	0.127
LH-(1-3) 9-11-08	28.8691		concentration	16.038	39.285	11.895	0.685	0.638	0.964	0.328	0.304	0.741	0.127
(1-3) AVERAGE	28.2573	71.743	**Avg**	16.283	39.6323	11.9143	0.6857	0.6383	0.96	0.329	0.304	0.742	0.1273
			LOI norm conc	11.6819	28.4333	8.54766	0.4919	0.458	0.689	0.236	0.218	0.533	0.0914
			rel std dev	1.32%	0.76%	0.19%	0.45%	0.09%	0.42%	0.35%	0.19%	0.31%	0.45%
LH-(1-2) 9-11-08	30.5046		concentration	13.302	41.936	10.492	0.624	0.653	0.959	0.205	0.3	0.797	0.127
LH-(1-2) 9-11-08	30.9618		concentration	13.097	41.748	10.447	0.611	0.645	0.958	0.205	0.294	0.809	0.125
LH-(1-2) 9-11-08	32.5504		concentration	12.615	40.751	10.394	0.602	0.638	0.949	0.204	0.292	0.78	0.127
(1-2) AVERAGE	31.3389	68.661	**Avg**	13.0047	41.4783	10.4443	0.6123	0.6453	0.955	0.205	0.295	0.795	0.1263
			LOI norm conc	8.92914	28.4795	7.17119	0.4204	0.4431	0.656	0.141	0.203	0.546	0.0867
			rel std dev	2.71%	1.54%	0.47%	1.81%	1.16%	0.58%	0.28%	1.41%	1.83%	0.91%
LH-(1-1) 5-8-09	30.1425		concentration	11.639	44.606	9.737	0.681	0.624	0.929	0.215	0.32	0.856	0.148
LH-(1-1) 5-8-09	31.1521		concentration	11.229	44.006	9.735	0.677	0.627	0.931	0.215	0.321	0.856	0.149
LH-(1-1) 5-8-09	32.9495		concentration	10.508	43.021	9.653	0.671	0.622	0.931	0.213	0.319	0.864	0.146
(1-1) AVERAGE	31.4147	68.585	**Avg**	11.1253	43.8777	9.70833	0.6763	0.6243	0.93	0.214	0.32	0.859	0.1477
			LOI norm conc	7.63034	30.0936	6.65849	0.4639	0.4282	0.638	0.147	0.219	0.589	0.1013
			rel std dev	5.15%	1.82%	0.49%	0.74%	0.40%	0.12%	0.54%	0.31%	0.54%	1.03%

Sample name	Loss On Ignition (%)	Sum of conc. (%)		AL203 AL %	SiO2 Si %	Fe2O3 Fe %	CaO Ca %	TiO2 Ti %	MgO Mg %	MnO Mn %	K2O K %	Na2O Na %	P2O5 P %
LH-(9-13) 9-15-08	32.3199		concentration	8.424	48.292	6.668	1.464	0.707	0.651	0.046	0.068	1.245	0.068
LH-(9-13) 9-15-08	35.0234		concentration	7.692	46.418	6.616	1.45	0.701	0.647	0.045	0.068	1.226	0.066
LH-(9-13) 9-15-08	37.1875		concentration	6.967	45.092	6.542	1.435	0.694	0.65	0.045	0.067	1.209	0.066
(9-13) AVERAGE	34.8436	65.156	**Avg**	7.69433	46.6007	6.60867	1.4497	0.7007	0.649	0.045	0.068	1.227	0.0667
			LOI norm conc	5.01335	30.3633	4.30597	0.9446	0.4565	0.423	0.03	0.044	0.799	0.0434
			rel std dev	9.47%	3.45%	0.96%	1.00%	0.93%	0.32%	1.27%	0.85%	1.47%	1.73%
LH-(9-12) 5-7-09	22.4109		concentration	11.465	51.761	8.695	2.948	0.729	0.747	0.056	0.057	0.992	0.076
LH-(9-12) 5-7-09	23.1814		concentration	11.411	51.102	8.678	2.929	0.725	0.743	0.056	0.056	0.983	0.073
LH-(9-12) 5-7-09	22.9177		concentration	11.425	51.324	8.678	2.942	0.726	0.745	0.056	0.057	0.989	0.075
(9-12) AVERAGE	22.8367	77.163	**Avg**	11.4337	51.3957	8.68367	2.9397	0.7267	0.745	0.056	0.057	0.988	0.0747
			LOI norm conc	8.8226	39.6586	6.70061	2.2683	0.5607	0.575	0.043	0.044	0.762	0.0576
			rel std dev	0.25%	0.65%	0.11%	0.33%	0.29%	0.27%	0.00%	1.02%	0.46%	2.05%
LH-(9-11) 9-15-08	24.1038		concentration	12.004	51.33	8.255	1.481	0.753	0.722	0.048	0.069	1.128	0.054
LH-(9-11) 9-15-08	23.5182		concentration	12.137	51.68	8.337	1.499	0.753	0.723	0.048	0.069	1.13	0.052
LH-(9-11) 9-15-08	24.009		concentration	11.975	51.476	8.249	1.483	0.749	0.721	0.047	0.07	1.114	0.053
(9-11) AVERAGE	23.877	76.123	**Avg**	12.0387	51.4953	8.28033	1.4877	0.7517	0.722	0.048	0.069	1.124	0.053
			LOI norm conc	9.16419	39.1998	6.30324	1.1325	0.5722	0.55	0.036	0.053	0.856	0.0403
			rel std dev	0.72%	0.34%	0.59%	0.66%	0.31%	0.14%	1.21%	0.83%	0.78%	1.89%
LH-(9-10) 5-8-09	25.7006		concentration	12.642	49.95	7.574	1.224	0.769	0.732	0.05	0.081	1.166	0.053
LH-(9-10) 5-8-09	24.7461		concentration	12.736	50.709	7.621	1.228	0.776	0.735	0.05	0.082	1.205	0.053
LH-(9-10) 5-8-09	25.3102		concentration	12.584	50.243	7.679	1.226	0.777	0.736	0.051	0.081	1.199	0.053
(9-10) AVERAGE	25.2523	74.748	**Avg**	12.654	50.3007	7.62467	1.226	0.774	0.734	0.05	0.081	1.19	0.053
			LOI norm conc	9.45857	37.5986	5.69926	0.9164	0.5785	0.549	0.038	0.061	0.889	0.0396
			rel std dev	0.61%	0.76%	0.69%	0.16%	0.56%	0.28%	1.15%	0.71%	1.76%	0.00%
LH-(9-9) 5-5-09	22.6759		concentration	10.938	53.841	6.952	1.655	0.842	0.858	0.052	0.058	2.017	0.047
LH-(9-9) 5-5-09	23.068		concentration	10.858	53.52	6.946	1.652	0.845	0.857	0.052	0.057	2.034	0.048
LH-(9-9) 5-5-09	23.7206		concentration	10.62	53.17	6.884	1.648	0.837	0.856	0.051	0.056	2.048	0.048
(9-9) AVERAGE	23.1548	76.845	**Avg**	10.8053	53.5103	6.92733	1.6517	0.8413	0.857	0.052	0.057	2.033	0.0477
			LOI norm conc	8.30338	41.1201	5.32332	1.2692	0.6465	0.659	0.04	0.044	1.562	0.0366
			rel std dev	1.53%	0.63%	0.54%	0.21%	0.48%	0.12%	1.12%	1.75%	0.76%	1.21%
LH-(9-8) 5-8-09	25.4127		concentration	10.704	52.336	8.191	0.8	0.976	0.663	0.064	0.077	0.658	0.054
LH-(9-8) 5-8-09	26.9336		concentration	10.253	51.374	8.112	0.796	0.964	0.655	0.062	0.075	0.659	0.053
LH-(9-8) 5-8-09	29.6428		concentration	9.416	49.586	8.044	0.778	0.966	0.663	0.062	0.075	0.653	0.053
(9-8) AVERAGE	27.3297	72.67	**Avg**	10.1243	51.0987	8.11567	0.7913	0.9687	0.66	0.063	0.076	0.657	0.0533
			LOI norm conc	7.35738	37.1336	5.89768	0.5751	0.7039	0.48	0.046	0.055	0.477	0.0388
			rel std dev	6.46%	2.73%	0.91%	1.48%	0.66%	0.70%	1.84%	1.53%	0.49%	1.08%

Sample name	Loss On Ignition (%)	Sum of conc. (%)		AL203 AL %	SiO2 Si %	Fe2O3 Fe %	CaO Ca %	TiO2 Ti %	MgO Mg %	MnO Mn %	K2O K %	Na2O Na %	P2O5 P %
LH-(9-7) 9-15-08	33.7476		concentration	9.044	44.587	9.498	0.614	1.01	0.601	0.089	0.084	0.6	0.064
LH-(9-7) 9-15-08	36.5892		concentration	8.102	42.769	9.438	0.605	0.992	0.601	0.088	0.083	0.611	0.063
LH-(9-7) 9-15-08	37.9807		concentration	7.502	42.021	9.389	0.607	0.999	0.595	0.088	0.083	0.613	0.064
(9-7) AVERAGE	36.1058	63.894	**Avg**	8.216	43.1257	9.44167	0.6087	1.0003	0.599	0.088	0.083	0.608	0.0637
			LOI norm conc	5.24954	27.5548	6.03267	0.3889	0.6392	0.383	0.056	0.053	0.388	0.0407
			rel std dev	9.46%	3.06%	0.58%	0.78%	0.91%	0.58%	0.65%	0.69%	1.15%	0.91%
LH-(9-6) 5-5-09	26.391		concentration	16.73	44.457	9.634	0.419	1.057	0.535	0.093	0.093	0.442	0.072
LH-(9-6) 5-5-09	26.1005		concentration	16.779	44.655	9.677	0.418	1.062	0.531	0.093	0.093	0.438	0.073
LH-(9-6) 5-5-09	26.1013		concentration	16.558	44.814	9.724	0.421	1.06	0.534	0.093	0.093	0.45	0.074
(9-6) AVERAGE	26.1976	73.802	**Avg**	16.689	44.642	9.67833	0.4193	1.0597	0.533	0.093	0.093	0.443	0.073
			LOI norm conc	12.3169	32.9469	7.14284	0.3095	0.7821	0.394	0.069	0.069	0.327	0.0539
			rel std dev	0.70%	0.40%	0.47%	0.36%	0.24%	0.39%	0.00%	0.00%	1.38%	1.37%
LH-(9-5) 5-5-09	25.0231		concentration	12.357	49.064	10.67	0.404	1.17	0.543	0.115	0.097	0.407	0.071
LH-(9-5) 5-5-09	24.9215		concentration	12.354	49.138	10.698	0.406	1.168	0.545	0.115	0.098	0.405	0.073
LH-(9-5) 5-5-09	25.1068		concentration	12.271	49.181	10.569	0.404	1.159	0.545	0.113	0.096	0.405	0.073
(9-5) AVERAGE	25.0171	74.983	**Avg**	12.3273	49.1277	10.6457	0.4047	1.1657	0.544	0.114	0.097	0.406	0.0723
			LOI norm conc	9.24339	36.8373	7.98243	0.3034	0.8741	0.408	0.086	0.073	0.304	0.0542
			rel std dev	0.40%	0.12%	0.64%	0.29%	0.50%	0.21%	1.01%	1.03%	0.28%	1.60%
LH-(9-4) 9-11-08	25.1475		concentration	11.924	49.126	10.792	0.528	1.19	0.545	0.114	0.093	0.407	0.081
LH-(9-4) 9-11-08	25.5674		concentration	11.909	48.841	10.696	0.524	1.176	0.543	0.112	0.092	0.407	0.083
LH-(9-4) 9-11-08	25.0393		concentration	11.946	49.242	10.773	0.528	1.188	0.543	0.113	0.094	0.398	0.083
(9-4) AVERAGE	25.2514	74.749	**Avg**	11.9263	49.0697	10.7537	0.5267	1.1847	0.544	0.113	0.093	0.404	0.0823
			LOI norm conc	8.91477	36.6789	8.03822	0.3937	0.8855	0.406	0.084	0.07	0.302	0.0615
			rel std dev	0.16%	0.42%	0.47%	0.44%	0.64%	0.21%	0.88%	1.08%	1.29%	1.40%
LH-(9-3) 9-11-08	26.1822		concentration	11.284	49.311	10.414	0.424	1.07	0.552	0.086	0.094	0.418	0.079
LH-(9-3) 9-11-08	27.059		concentration	11.144	48.736	10.28	0.423	1.053	0.552	0.087	0.096	0.409	0.079
LH-(9-3) 9-11-08	27.4286		concentration	11.09	48.315	10.384	0.418	1.064	0.549	0.087	0.095	0.408	0.079
(9-3) AVERAGE	26.8899	73.11	**Avg**	11.1727	48.7873	10.3593	0.4217	1.0623	0.551	0.087	0.095	0.412	0.079
			LOI norm conc	8.16834	35.6685	7.57372	0.3083	0.7767	0.403	0.063	0.069	0.301	0.0578
			rel std dev	0.90%	1.02%	0.68%	0.76%	0.81%	0.31%	0.67%	1.05%	1.34%	0.00%
LH-(9-2) 5-5-09	30.8184		concentration	12.696	44.924	9.003	0.333	1.003	0.483	0.081	0.092	0.395	0.087
LH-(9-2) 5-5-09	31.3357		concentration	12.598	44.624	8.906	0.334	0.986	0.483	0.08	0.092	0.392	0.086
LH-(9-2) 5-5-09	31.9783		concentration	12.236	44.212	9.018	0.332	1.004	0.487	0.082	0.09	0.389	0.087
(9-2) AVERAGE	31.3775	68.623	**Avg**	12.51	44.5867	8.97567	0.333	0.9977	0.484	0.081	0.091	0.392	0.0867
			LOI norm conc	8.58468	30.5965	6.15933	0.2285	0.6846	0.332	0.056	0.063	0.269	0.0595
			rel std dev	1.94%	0.80%	0.68%	0.30%	1.01%	0.48%	1.23%	1.26%	0.77%	0.67%
LH-(9-1) 9-11-08	35.0699		concentration	9.542	43.03	9.618	0.337	1.096	0.508	0.124	0.097	0.392	0.095
LH-(9-1) 9-11-08	37.8063		concentration	8.775	41.242	9.438	0.335	1.091	0.511	0.122	0.096	0.397	0.097
LH-(9-1) 9-11-08	39.7616		concentration	7.992	40.109	9.421	0.33	1.08	0.509	0.121	0.096	0.399	0.094
(9-1) AVERAGE	37.5459	62.454	**Avg**	8.76967	41.4603	9.49233	0.334	1.089	0.509	0.122	0.096	0.396	0.0953
			LOI norm conc	5.47701	25.8937	5.92835	0.2086	0.6801	0.318	0.076	0.06	0.247	0.0595
			rel std dev	8.84%	3.55%	1.15%	1.08%	0.75%	0.30%	1.25%	0.60%	0.91%	1.60%